13.—Mulga (North) Chondritic Meteorite Shower, Western Australia

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Abstract

Further recoveries in 1970 and 1971 of the stony meteorites Mulga (south), Billygoat Donga, and Mulga (north) demonstrate the partial overprintings of their strewnfields, though the sequence of arrival is uncertain. A total of 781 fusion-crusted stones or fragments of Mulga (north) of aggregate weight 19.5 kg have been recovered from an elliptical strewnfield of dimensions 6.1 x 1.2 kilometres. Detailed field records of the circumstances of occurrence and sites were maintained.

The degrees of entirety of the stones and stages of development of fusion crusts have been defined and are described for individual stones by a system of code letters; textures and minor features of the crusts are briefly noted. The stones stably oriented in flight have been nominated and the criteria used are stated. The sphericities of individual stones, their weights, and where possible the weights when restored to a fully primary crusted condition have been determined.

The degree of fragmentation does not appear to have been as great as for showers such as Holbrook. A complex series of aerial fragmentation events is indicated for Mulga (north) by the frequent occurrence of fusion crusts of various developmental stages on different facets of the one stone; re-assembled stones provide further evidence of the step-wise nature of the breakdown; the spalling of thin flakes from the surfaces also contributed. The applicability of the Gaudin relation to the size distribution has been examined, and an attempt made to isolate the products of the initial fragmentation for similar study.

The field distribution has been treated only qualitatively but a detailed tabulation of the surface features, weights, and morphology together with the co-ordinates of the sites of find of all pieces has been prepared as the basis for study of the field distribution and of the factors which could influence it.

Introduction

Details of the stony meteorites Billygoat Donga, Mulga (south), and Mulga (north), and of their recoveries during the period 1962-66 from a small area centred 95 km N.N.E. of Haig, Western Australia, are available in literature, but a brief summary is desirable before detailing the recent recoveries. In 1962, T. and P. Dimer found three small meteoritic stones close together about 11 km north of Billygoat (or Mulga) Donga, which is located ca. 30° 08′S., 126° 22′E. They lost two of the stones and the remaining one became known as Billygoat Donga (I). In 1963, the A. J. Carlisles Snr and Jnr. noted a shallow depression in the ground to the north of Billygoat Donga, and because it differed in some way from other natural features of the area, they suspected a meteorite crater, searched and found within it a 16 g fragment of stony meteorite. No petrographical examination of this stone was possible, but it was recorded as Billygoat Donga II. The stone was returned to the finders and was subsequently lost.

Late in 1963 the writer sought unsuccessfully the crater described by the Carlisles, but found instead three fitting fragments of stony meteorite which were initially recorded as Billygoat Donga III. In the following year he found five more fragments of the same type, and in extending the area of search found a concentration of 59 stones of distinctly different morphology. Subsequent petrographical examination confirmed the distinction, though both are olivine-bronzite chondrites with fayalite index 18, and simultaneously demonstrated that they were unrelated to Billygoat Donga I which is an olivine-hypersthene chondrite with fayalite index 25. Billygoat Donga III was re-named Mulga (south), and the concentration of 59 stones together with a further 12 found in 1966 was named Mulga (north). Billygoat Donga thus remained represented only by the small stone found by T. and P. Dimer (McCall and de Laeter 1965; Cleverly 1965; McCall 1968; McCall and Cleverly 1968).

The extended distribution of 13 more stones of Mulga (north) recovered during a brief visit in 1967 (bringing the total to 84) made it increasingly likely that the known material was but a fraction of a considerable shower. A field trip in December 1970 had as one of its principal objectives the collecting of Mulga (north) and the delineation of its field of occurrence. It was expected that search would be facilitated by minimal grass cover in the summer season, though climatic conditions might be extreme; both expectations were fully realised. In nine days, three searchers recovered 325 pieces of meteorite from within an elongate area of complex shape and of dimensions exceeding 4 x 1 kilometres. From their distinctive morphologies 321 pieces were recognised as Mulga (north) and 3 as Mulga (south). A single piece resembled the Billygoat Donga (I) stone which had been found about six kilometres further north eight years previously. In response to a request for determination of the fayalite index of the olivine, Dr. Brian Mason stated (pers.comm)—"a typical hypersthene chondrite with olivine composition Fa 25 . . . indistinguishable from Billygoat Donga; even the degree of weathering is the same". A triple overprinting of the strewnfields of these three meteorites had thus been demonstrated.

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When a detailed plot of these occurrences was prepared, it was realised that the gaps and apparent anomalies in the distribution of Mulga (north) might be only deficiencies in the data. A further field visit was therefore made in December, 1971 to concentrate search on gaps and critical areas. As the result of a dry year without seasonal growth of grass the ground surface was ideal for search (Fig. 1). The same three persons found 391 pieces of meteorite in 9½ days, extending the strewnfield to a narrow ellipse of dimensions 6.1 x 1.2 km and of area 5.4 square kilometres. The recoveries included 13 pieces of Mulga (south), a fragment of Billygoat Donga fitting the stone found in 1970, and a small stone since named Mulga West. The position may now be summarised whilst referring to Figure 2.


Figure 1.—View westward in the middle section of the strewnfield of Mulga (north) meteorite, about 95 km N.N.E. of Haig, Western Australia. Trees in left middle distance are in Three Mile Donga (see Fig. 2). Well-used vehicle track at right connects the main line of survey stations extending roughly along the axis of the strewnfield. Photographed in December, 1971.

1. Mulga (north) is known by 781 pieces of total weight 19.5 kg and its strewnfield can be reasonably defined except at the ends. The direction of flight was eastward. Very small individuals comparable with the Pultusk and Holbrook "peas" may exist at the western end but extreme climatic conditions mitigated against their observation and recovery. A few individuals weigh less than one gram, the lightest 0.37 gram. It is likely that a few large stones are still in situ within and beyond the eastern end of the known strewnfield, and that some of them might be completely embedded. Limitations of time precluded a detailed walking search, and the heaviest stone (the easternmost), was recovered during a reconnaisance type search by vehicle on widely spaced grid lines; only two fifths of its vertical dimension was above ground surface.

2. The Mulga (south) meteorite is known by 24 pieces of which all except five have the typical morphology of the earlier known material, i.e. are fragments with discontinuous areas of dark, very thin, fusion crust. The other five have additionally some remnants of an older, smoothly curved, primary type surface. The total known weight is 894 grams. The extent of the strewnfield and direction of flight are not evident. The rather curious distribution shown in Fig. 2 is the result of detailed search within the strewnfield of Mulga (north) coupled with only the most casual search or none at all in most parts of the surrounding area.

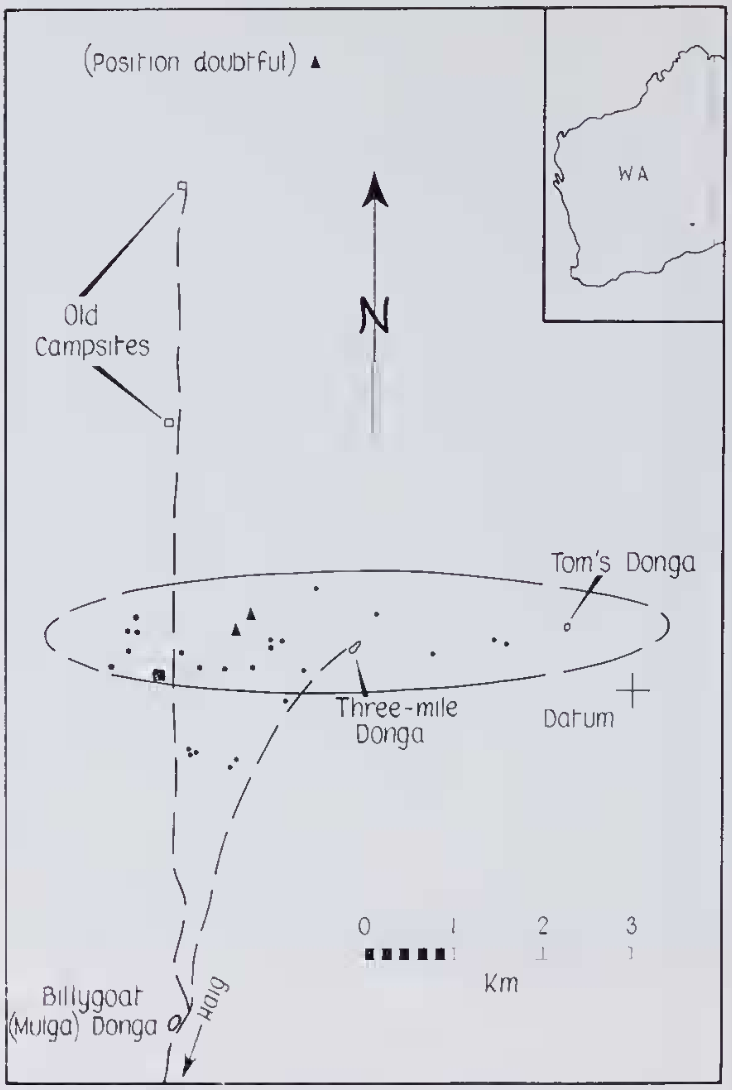

Figure 2.—Sketch map showing location of the approximately elliptical strewnfield of Mulga (north) stony meteorite in relation to Billygoat Donga, Western Australia. Sites of find of the Mulga (south) meteorite (dots), the Billygoat Donga meteorite (triangles), and the Mulga West meteorite (square symbol) illustrate the overprinting of their strewnfields. Coordinates of individual sites of find are measured relative to the datum indicated.

3. The Billygoat Donga meteorite is known by three pieces of total weight 633 grams. The site of find of the original stone is known only very approximately. The other two pieces, which were found 230 m apart during different field visits, fit to form an almost complete, fusion-crusted individual of nearly 500 grams. The form of the strewnfield is unknown. Because the original stone was reported to be one of three small individuals found close together, and the later finds constitute a much heavier and apparently isolated individual, the general direction of flight might have been southerly.

4. The Mulga West meteorite is known by a single, small, almost brick-shaped stone of weight 169.2 g found near the western end of the Mulga (north) strewnfield (Fig. 2).

Note added Aug 10, 1972. Dr. G. J. H. McCall advises (pers. comm.) that Mulga West is of rare type and thus unrelated to the other three common chondrites. Four meteorites are therefore represented within the Mulga (north) strewnfield.

Mulga (north) is less weathered and is a later arrival on earth than Mulga (south) (McCall and Cleverly 1968). Billygoat Donga is also somewhat weathered but the few pieces known do not appear to be as deteriorated as some of the more recently recovered stones of Mulga (north). It might be the most recent arrival or intermediate in age. Comparisons are made difficult because Billygoat Donga is of a different petrological type to the other two. A comparison of the specific gravities of stones of comparable weights with the probable values for fresh meteorites (Table 1) is inconclusive.

All three meteorites are "finds" of common chondrites and their material value is relatively small, but all except 1 of the 809 pieces were found by persons of scientific training, and the maintenance of unusually complete records of the circumstances of occurrence and locations has been possible. These data are especially valuable for Mulga (north) and should provide a partial answer to the plea of Frost (1969) for such details.

It is surprising that after about 70 man-days have been spent in the area, the crater which was seen by the Carlisles in 1962 and which initially drew attention to the area, remains unrecognised. The Carlisles, with the accumulated knowledge of three generations and over half a century of familiarity with the Nullabor Plain are probably the best qualified of anybody to decide that a feature is unusual. Their unparallcled record as finders of meteorites (McCall and Cleverly 1970 Table 1) attests to the acute powers of observation they have needed to develop in this generally inhospitable region. Moreover, they have since, in 1966, recognised the impact crater of the Pannikin meteorite and collected small chips of stony meteorite from within it (McCall and Cleverly 1968). With the advantage of hindsight, the Billygoat Donga II stone from the crater resembled Mulga (north), but it is difficult to believe that a crater-like feature of the order of 10 m diameter could have escaped notice within the known strewnfield.

A by-product of the search was the recovery of 102 australites (tektites), or about 19/square kilometre. Their total weight is 127 grams. Nearly all are fragments and several are clearly artefacts; all five of those selected for expert examination were confirmed as artefacts by C. E. Dortch (pers. comm.). Such artefacts were evidently discarded by itinerants or date from times of more humid climate because present sources of water are ephemeral. An occasional clay-floored donga* such as Billygoat Donga could hold shallow water only very briefly; no rock holes of significant water capacity are known in the area.

Mulga (north) meteorite

Reference will be made in the balance of this paper to Table 2 which, as reproduced, contains only those stones specifically referred to in the text and a few others illustrating types. It is neither practicable nor necessary to reproduce the full table of 781 items which is of interest principally to the specialist student of the mathematics of fragmentation and distribution. A copy of the full table is available on application to the Director, Western Australian Museum, Perth, Western Australia.

Table 1.

Comparison between specific gravities of meteorites as found and values of unweathered types

Meteorite and Type	Specific gravities of pieces in weight range 90–145 grams	Weighted mean of preceding column	Range of specific gravity for unweathered meteorites of same type (Mason 1962)	Range of mean weathering effect (Col. 4 minus Col. 3) and maximum individual effect
Mulga (south) CBr	3.333, 3.364	3.35	3.6—3.8	0.25 to 0.45 0.47
Billygoat Donga CHy	3.380, 3.434	3.41	3.5—3.6	0.09 to 0.19 0.22
Mulga (north) CBr	3.590, 3.600, 3.608, 3.605, 3.602, 3.612, 3.604, 3.585	3.60	3.6—3.8	0.00 to 0.20 0.21

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* The term donga is used on the Nullarbor Plain for shallow, sometimes extensive, sink features of the limestone surface. Many dongas contain growths of trees (Fig. 1), and being campsites favoured by itinerants, are often named by them, though few such names have official recognition.

Table 2.

Field numbers, classification, weights, orientation, sphericity, and coordinates of sites of find for some stones of Mulga (north) meteorite

Field number	Classification	Weight g	Weight as CP g	Orientation	Sphericity	Westing km	Northing km
3	FPU	77.4	....	....	0.70	3.76	0.61
27	CP	73.6	73.6	X	0.75	3.18	0.72
33	CPT	111.3	129.3	X	0.51	3.57	0.58
65	CPS	27.3	....	....	0.69	3.84	0.85
111	DPTU	336.4	340.1	X	0.78	2.75	0.91
118	CPS	87.3	....	X	0.61	3.04	0.45
128	CPS	169.1	....	X	0.69	2.15	0.49
135	CPT	22.9	....	....	0.60	3.21	0.39
139	FPUT	23.8	....	....	0.63	2.27	0.60
140	FTPU	4.7	....	....	0.78	2.28	0.61
141	CTP	4.2	....	....	0.53	2.28	0.60
146	CPT	22.1	....	....	0.42	3.93	0.78
149	FPTSU	99.1	....	....	0.51	2.89	0.44
150	DPSTU	58.9	....	....	0.71	2.91	0.43
155	FPUT	151.3	....	....	0.63	4.10	0.98
159	CPT	0.5	....	....	0.48	2.20	0.84
164	CP	205.9	205.9	X	0.75	2.13	0.64
167	CP	188.1	188.1	X	0.69	1.88	0.77
174	CPT	60.0	61.5	....	0.69	3.51	0.37
176	FSUTP	56.4	....	....	0.53	3.52	0.40
199	FPSU	44.9	....	....	0.62	3.80	0.92
208	CTSP	188.3	....	....	0.73	1.55	0.56
209	CTSP	245.7	....	....	0.83	1.42	0.62
218	CPST	14.5	16.3	X	0.68	4.22	0.71
245	CPT	4.8	4.8	X	0.57	4.81	0.71
260	CPS	7.2	7.2	X	0.71	4.98	0.58
309	CPST	5.0	5.0	X	0.69	5.06	0.65
321	CP	0.4	0.4	....	0.75	5.11	0.60
390	FPTU	4.8	. .	....	0.72	5.47	0.52
448	DPU	0.4	0.4	....	0.60	5.64	0.56
469	CPT	5.5	....	....	0.51	4.63	0.29
473	DPTU	2.6	3.0	....	0.88	4.62	0.52
499	FPU	64.7	....	....	0.66	3.59	0.71
533	CPT	347.9	371.0	....	0.66	2.15	0.35
542	CP	533.4	533.4	....	0.77	2.06	0.73
638	CPT	8.7	9.3	X	0.61	5.25	0.88
677	CPT	64.7	64.9	X	0.66	3.79	0.19
758	CP	4.9	4.9	X	0.67	5.19	0.75
807	DPU	2095	2110	...	0.68	0.05	0.60
822	CPT	2.5	2.5	...	0.63	4.94	0.47

Field occurrence

Stones are identified in Table 2 by their field numbers (column 1). Most of the numbers missing from the full table are accountable either to other meteorites or to spurious material. In the field, fragments showing some degree of weathering and separated by distances of up to one or two tens of centimetres were regarded as products of disintegration and were recorded as a single stone. Likewise, when two or three fitting stones not showing advanced weathering were found up to a few metres apart, they were accepted as impact fragments and recorded as one stone; the situation was especially clear when such a group was found relatively isolated from other stones. As a result of this recording procedure, both the number of stones and the amount of uncrusted meteorite surface attributable to impact or weathering have been minimised.

More than 90% of the stones lay on the surface of the ground or were embedded only to the extent of inequalities of the contacting surfaces. The remainder were embedded from one quarter to (rarely) as much as three quarters of their vertical dimension, and of those so embedded many are judged to have been oriented stones in flight position. The general shallowness of the embedding and some of the other features—such as the infrequent occurrence of regmaglypts—result from the generally small size of the stones.

The survey of the strewnfield was made by prismatic compass and pacing, a method adopted initially of necessity because the writer was unaccompanied when the first 59 stones were found. Use of this procedure continued during later field trips because atmospheric refraction effects restrict so severely the times of the day when instruments can be used, and because the opportunities for field work in this area are very limited. The two original survey stations were supplemented during later searches to form a chain of 16 stations with a branch line of one or two stations to each side of the main line where required. From these stations all sites were paced in. The speedometer reading for a vehicle traverse along the main line of stations, after adjustment for known error, differed from the plotted length by 3%. A large overall error is therefore unlikely, and because the pacing was done by the same person on all five occasions, internal distances should be in proportion and any errors of the same order.

Co-ordinates of individual sites of find (last two columns of Table 2) are westings and northings in kilometres from an arbitrary datum located 0.05 km east of the easternmost site (the heaviest stone) and 0.05 km south of the southernmost site (see Fig. 2). Because the axis of the strewnfield is approximately west-east and the direction of flight was eastward, the westings are in the form which has become conventional for the mathematical description of lateral distribution, while the northings are an expression of the distribution transverse to the axis. Co-ordinates have been rounded to the second decimal place (the nearest 10 m) and as a result of this, a few pairs of sites have identical co-ordinates.

It is believed that the stones were found close to their original points of fall. Ground slopes are generally very low and, to judge by the insignificant drift of weathering fragments from their parent stones, the amount of movement of the stones is likely to have been very small. The aboriginal inhabitants appear to have made no use of the stones.

Features of individual stones

Stones generally have the angular, faceted yet smooth form which results from fragmentation followed by development of fusion crust, but many stones also have surfaces free of crust or thinly veiled by crust.

The degree of entirety of the stones, the stage of development of the fusion crust(s), and the relative areal abundances of the crust types are indicated by a system of code letters in column 2 of Table 2.

The degree of entirety is expressed by either C, D or F. C denotes completely fusion-crusted stones, irrespective of the degree of development of the crust(s). D indicates stones with one, or occasionally more than one surface lacking crust, and having a profile such that a probable reconstruction to fully crusted form can be made. This type of stone is generally much more than 50% of the mass of the original but lacks a "cap piece" or "edge piece". F indicates fragments with at least one surface free of crust and whose profile does not allow a confident reconstruction of the shape; some of these are the type of fragment lacking from category D stones.

The degrees of development of crust are indicated by P, S, and T. P indicates the primary crust of smoothly curved surfaces from which all except centimetre-sized inequalities have been smoothed out. It is close-textured or knobby, except for localised developments of scoriaceous or striated texture, particularly on stones which were stably oriented in flight (for textural terms see Krinov 1960). S denotes surfaces of the second kind ranging from finely rippled surfaces with crusts which barely veil the roughness of the fracture to coarsely wavy surfaces which are not always clearly distinguishable from primary crust, though the distinction is easily made when the two types occur on different facets of the one stone. These crusts do not commonly develop knobby texture, presumably because some minimal degree of development is necessary before the superior refractoriness of disseminated metallic grains can be expressed in that way. T denotes tertiary crusts covering the developmental range:—"smoking" of the surface, discontinuous films with mineral visible through gaps or through the crust, films through which mineral is only occasionally seen, complete crust which fails to hide the roughness of the surface and has an almost hackly appearance. Beyond this stage is the finely rippled crust of the secondary type. The nomenclature is similar to that of Foote (1912) for the Holbrook shower except that the hackly type is here placed in the tertiary category.

In very numerous cases the creep of crust over the edge of a later fracture surface indicates that a tertiary crust should be sought and that, even if such a crust is not detected, the surface must have been produced by aerial fragmentation. The creep of fusion crust is sometimes observed in the direction away from the surface of lesser crust development, e.g. from tertiary over primary surface on stone No. 99. This results from the adoption of an appropriately oriented flight position following the later fragmentation.

The letters P, S and T may be applied to different facets of the one stone representing surfaces produced by successively later fragmentation events or surfaces developed simultaneously on facets of an oriented stone enjoying different degrees of protection during atmospheric flight.

The system is admittedly subjective but a degree of sureness is developed by familiarity with the material. During second and subsequent re-examinations, most of the surfaces initially classified as doubtful could be classified with confidence. It is important to appreciate that even if the surface types were classified perfectly, there would be no implication that the surfaces of a given (say, secondary) type had developed following the same fragmentation event; rather, they are surfaces which have been exposed to similar sets of conditions possibly as the result of quite a number of different events.

U indicates uncrusted surfaces. By definition this letter cannot occur in combination with C and must occur with D or F. It might therefore appear unnecessary but it is required for the following purpose. During a final review of the material the letters P, S, T and U were arranged in sequence of decreasing surface area. Each of the three types C, DU and FU can occur in seven combinations with crust types, e.g. CP, CS, CT, CPS, CPT, CST, CPST, but with the permutations arising from surface abundances the number of possible expressions is considerably increased. About 40 different expressions have been used.

Regmaglypts, usually shallow and of small size (1-2 cm) are sparsely present on only about 3% of the pieces, usually stones of weights exceeding 100 g or fragments which have clearly been derived from the larger stones.

Most stones show surface cracking ranging from single cracks to a complete breadcrust pattern initiated during the cooling of the surface in the later stages of atmospheric flight. A gaping breadcrust pattern occurs seldom, usually on the weathered and swollen underpart of a stone which has been embedded in the ground.

Because shape factors almost certainly affect the distribution, it is desirable that they be quantified, but such factors are difficult to assess. Stones which are stably oriented in flight can be expected to fly more truly and further than those which tumble and to be less affected by transverse winds. Much the same is probably true of stones whose shape approaches the equidimensional compared with those of comparable weights which are tabular or otherwise inequidimensional.

A stable flight orientation (shown by X in column 5 of Table 2) is indicated by the presence of one or more of the following criteria:—

1. Roughly conical, pyramidal or wedged shapes embedded with point or edge down. Though the views illustrated in Fig. 3 have considerable similarity, they represent a wide variety of three-dimensional shapes. No. 111 (Fig. 3A) is representative of the conical and pyramidal stones; No. 128 (Fig. 3D) is a split pyramid which has developed secondary crust on the broken surface; No. 33 (Fig. 3E) is a roughly tabular stone which, despite losses and development of tertiary crusts, appears also to have been oriented in flight; No. 167 (Fig. 3F) is typical of a variety of stones with lozenge-shaped sections; it is roughly triangular with point down in the third (unillustrated) dimension; others with this type of section include more elongate and hence prismatic stones, which evidently had a leading edge in flight (e.g. No. 118). This criterion was not accepted as sufficient in itself because exceptions almost certainly occur. For example, the relatively thin, triangular No. 499 was embedded with the sharpest angle of the triangle downward, but such is an unnatural orientation for a stone having so much surface. No. 164 is oval in plan view, lozenge-shaped in section, and embedded in the

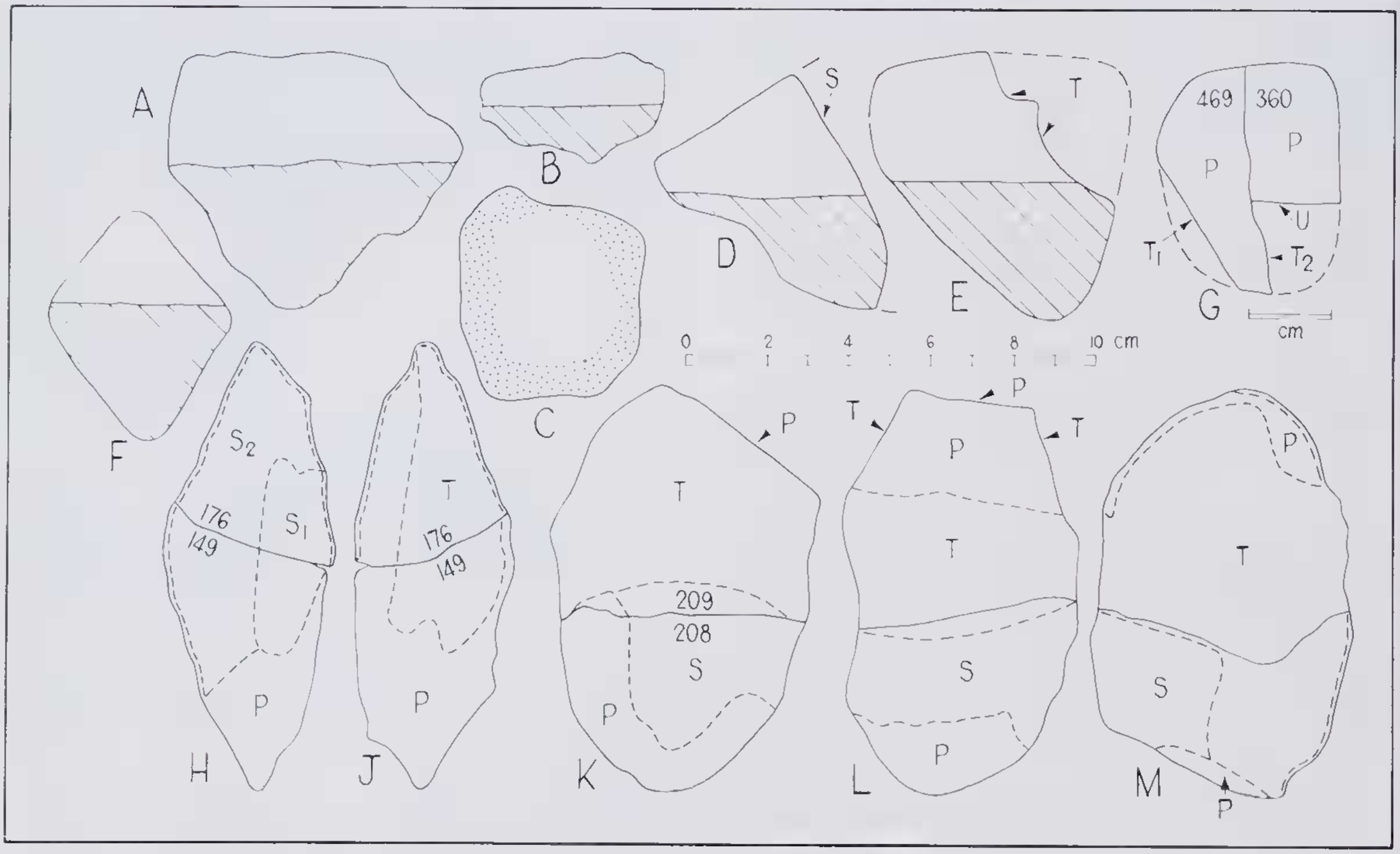

Figure 3.—Sketches of Mulga (north) meteoritic stones. A.—Profile of No. 111 showing soil line, embedded portion shaded. B.—As for A, No. 677. C.—Base of No. 677 showing encroachment of scoriaceous crust from the sides. D.—As for A, No. 128. E.—As for A, No. 33. F.—As for A, No. 167. G.—Composite stone 390/469, restored parts indicated by broken lines, surface types lettered as in text. H. and J.—Two views of composite stone 149/176 showing surface types. K. to M.—Three views of composite stone 208/209, which is roughly triangular in midsection, showing surface types. The scale applies to all except G, for which a one-centimetre bar is shown.

manner of Fig. 3F, but the best-developed regmaglypts are on the surface found uppermost; it was probably oriented in flight but not in the position as found.

2. Regmaglypts of appropriate distribution, elongation, or alignment. The almost cuboidal No. 542 is shown to have been oriented by the regmaglypts and the distribution of scoriaceous crust rather than by its being embedded "edge on".

3. Textural types characteristic of frontal, lateral, and rear surfaces with appropriate distribution (Krinov 1960). In particular, small areas of scoriaceous crust to one side of surface irregularities or as a rim encroaching on one facet of a stone are common. Thus the flatly pyramidal stone No. 677 has regmaglypts on the front and a scoriaceous zone 5-10 mm wide rimming the flat base (Fig. 3 B, C). Examples of more sharply defined scoriaceous borders are on the bases of the flatly conical No. 758 and the almost tabular No. 638. It is necessary to distinguish this creep of crust from the much more general case when the stone was tumbling in flight. The regular width, and hence the apparently sharp edge of the overflowed crust on oriented stones is usually diagnostic. The striated texture (thin streams of melt glass) is occasionally detectable as a radial pattern on the apices of conical stones or over their lateral edges. Spattered droplets on the lee side of high points, as in the case of scoriaceous crust, occasionally provide additional evidence.

4. The combination of a primary crust with one of lesser development on a significant facet such as the base of a cone. Because there are other possible interpretations, such stones were not accepted as oriented without confirmatory evidence.

From a consideration of the above criteria 116 stones have been nominated as oriented during at least some part of their atmospheric flight. On a further 27 stones the evidence was less convincing. The oriented stones comprise at least three classes; firstly, those of category CP; secondly, those whose orientation during the earlier stage of flight preceding a secondary fragmentation is indicated by regular but incomplete rims of scoriaceous crust terminated abruptly against facets of lesser crust development; thirdly, those which were oriented only after a secondary fragmentation as is shown convincingly in several cases by rims of crust and patches of scoria directed away from surfaces of lesser crust development on to secondary or primary crust. A fourth class of stones which were oriented before fragmentation and re-oriented afterwards is doubtfully represented by two examples.

The various expressions of sphericity used in sedimentary petrology (Pettijohn 1957) describe with varying degrees of success, the approach to spherical shape, i.e. to minimal surface area per unit volume. None of these expressions is highly satisfactory for angular fragments of low roundness. Thus when applying the Zingg system to angular objects the manner of taking the dimensions may require measurements between diagonally opposite corners or obliquely inclined edges. Following are the results of measuring 100 Mulga (north) stones by this method:—

Class I (tablets)	27
Class II (equidimensional)	53
Class III (prisms)	4
Class IV (blades)	16

Because the tabular specimens are partly accountable to flat "cap pieces" and to surface spalls, it is likely that the principal fragmentations yielded fragments amongst which "equidimensional" shapes considerably outnumbered the others combined. Twelve of the sixteen CP stones included in the above sample belong to Class II.

The method used to determine the sphericities recorded in column 6 of Table 2 was the ratio d_1/d_2 where d_1 is the diameter of the sphere of equivalent weight (calculated from weight and density), and d_2 is the diameter of the circumscribing sphere. The method has the merit of simplicity but does not distinguish between the broad classes of inequidimensional shape. Further, the largest dimension is not uncommonly smaller than the diameter of the circumscribing sphere, a situation which arises also, though in the writer's experience not as frequently, in materials which have suffered some rounding by terrestrial erosion.

The spericity values range from 0.42 to 0.88 but only 11 stones have values less than 0.5 and only a further 11 have values greater than 0.8. The mean value is 0.62. As had been anticipated, the mean sphericity value for stones of category CP is distinctly higher, being nearly 0.70.

Most of the common crust types and minor surface features have been mentioned inter alia above, and may now be summarised together with some rarer features. Knobby and close textured crusts predominate; scoriaceous texture is of common occurrence but very limited in area on any one stone; the striated texture is uncommon and the net texture comprising two sets of crossing striae is rare; only a single good example of porous texture was observed occurring centrally to a rim of scoriaceous crust on the rear surface of an oriented stone, an unusual location. Spattered droplets of glass occur but not in the abundance and size which constitutes warty texture, probably because of the generally small size of the stones. Surprisingly for a meteorite with a pronounced degree of recrystallization (McCall and Cleverly 1968), chondrules are not uncommonly visible in the fusion crusts as rounded and more lustrous patches—the so-called "oily stains"—and they sometimes show some detail of their internal constitution. A good example is the large (nearly 5 mm) barred chondrule visible in the primary crust of stone No. 27.

The weights of the stones (column 3 of Table 2) range from 0.2 g to 2095 g with frequency as follows:

>1000g	1
1000 to 100.1 g	31
100 to 10.1 g	253
10 to 1.1 g	442
1 to 0.2 g	54

Column 4 of Table 2 shows the weight of the stone when restored to category CP for a purpose explained in the next section. Such restorations are not possible for stones of category F, nor generally possible for any stone which does not have primary crust as the most abundant surface type, i.e. has P as the second letter in the classification. Estimates become increasingly hazardous if more than two surface types are present. In practice, estimates could be made for some of the stones of categories CPS, CPT, DPU, DPSU, DPTU, and rarely for others. Estimates were made by completing the form with modelling clay, weighing the clay and applying a factor to correct its weight to that of meteorite. When completing the shape, advantage was taken of the observation that most of the meteorite surfaces are flat or convex; when concave, they are usually only gently so. The weight of restored material was generally less than 10% of the weight of any individual and is collectively only 3% of the weight of all restored stones.

Fragmentation

If the pieces of Mulga (north) of mean weight 25 g were derived from a single mass of more than 19.5 kg, aerial fragmentation was clearly a highly effective process. However, for the Holbrook shower (Foote 1912; Nininger and Nininger 1950) the mean weight of the known fragments is less than 14 g though the total weight is 235 kilograms. From the mathematical estimates of the number of fragments and total mass of the Pultusk shower (Lang and Kowalski 1971) the mean fragment weight would be about 11 g for an estimated mass of two metric tons (the known material has only about one tenth of that weight).

Mean weights, at best, are an inadequate basis for comparison and there are also enormous differences in the efficiencies of collection of these showers. Foote (op.cit.) employed more than 100 people for two months in collecting Holbrook and he was followed after an interval of some years by the highly organized parties of Dr. Nininger, who made several visits; scarcely 1% of that time has been spent upon collecting Mulga (north), though the dimensions of the two strewnfields (and also that of Pultusk) are of the same order of size (Krinov 1960). The degree of fragmentation of Mulga (north) may therefore appear to have been considerably exceeded in other showers but an intensive collecting campaign might well lead to a reassessment. At least until a change in seasonal conditions brings itinerant workers to the Billygoat Donga area, the site of Mulga (north) is almost inviolable.

Amongst "finds" of meteorite showers, only Plainview is superior to Mulga (north) both numerically and in total mass, but the Plainview stones are of a distinctly larger order of size.

A consideration of the fusion crust types on Mulga (north) stones shows that series of fragmentation events were necessary for the reduction of the material to such a small average size. Individual stones weighing only one or two tens of grams may show on different facets the whole series of surface types (P, S, T, U), and the tertiary crusts may show distinctly different developmental stages on facets of the one stone. Stones which have been re-assembled from separated pieces warrant description in some detail because they are informative both as to the reduction process and the field distribution.

Pieces Nos. 3 and 199 (for details see Table 2) were found more than 300 m apart (Fig. 4). They fit together on uncrusted surface and the composite stone has classification CPS. No. 65 fits approximately upon the secondary surface (a close fit is not to be expected when opposing surfaces have each attained the rippled secondary stage of development). The fully re-assembled stone has classification CP. It appears therefore that following the initial fragmentation, a piece which weighed rather more than 150 g and which was developing primary crust, lost one end. The surfaces thus exposed ultimately developed secondary crust. At a distinctly later stage of flight, the larger piece broke across.

The pieces Nos. 149 and 176 fit together on uncrusted or thinly tertiary-crusted surfaces (Fig. 3 H, J). The composite stone has primary crust at both ends, but large scars with secondary and tertiary crusts transgress the line of join. The original fragmentation thus yielded a mass which acquired primary crust and this was followed on at least two separate occasions by losses of flat slabs from the sides; finally the remnant broke across. The composite 208/209 (Fig. 3K-M) has a similar but more complex history, having primary crust at the ends with secondary and tertiary crusts of various developmental stages in a central girdle representing losses at various stages prior to the final breakage.

Specimen No. 390 fits No. 469 on part of the tertiary surface (Fig. 3G). The composite has classification DPTU, the weight as CP can be estimated reliably, and the history reconstructed. A tabular stone weighing about 14 g first lost a corner piece weighing about 1.8 g (not recovered); the scar has well developed tertiary crust (T_1). Distinctly later, the main piece broke across and the edges of the break show creep of crust over the edge of the fracture surface (T_2). No. 469 is one of the two pieces, but the other piece broke again and its larger fragment is No. 390; the smaller fragment of weight ca. 1.7 g was not recovered.

Specimen No. 533 has a shallow scar on one face on which No. 135 fits perfectly to form a low bulge above the surface and to make an almost complete stone. Complementary parts of the contacting surfaces show strong shearing. Possibly as a result of surface heating the upstanding portion burst out of the surface of the parent mass which was subsequently found more than one kilometre to the east of it (Fig. 4).

For simplicity in the above accounts, the development of primary or other crusts has been recounted as if each was a distinct episode; in fact, the further development of the primary crust continued simultaneously with the development of secondary and tertiary crusts on more newly exposed surfaces.

It is remarkable that pieces as light as 14 g should break and break yet again. Loss of "spalls" from the surfaces was also an important mechanism contributing to the break-down. Stones as light as 2 g show circular or ovoid scars of a few millimetres dimensions resulting from such losses. Often the losses are no more than small patches of crust. The scars are commonly partially healed by tertiary crusts. The weight of material necessary for the restoration of such scars is often insufficient to affect the weight of the stone to the nearest 0.1 g (e.g. No. 822).

Metallurgical studies of comminution include experimental investigations of the influence of the impact velocity and other variables upon such features as the reduction ratio, fragment shapes, and size distribution of the products. It would be of interest to examine the Mulga (north) material in the light of such experimental results, but comparisons are hindered by the complexities and uncertainties of meteorite fragmentation processes. The writer subscribes to the general concept that a meteorite entering the atmosphere at cosmic velocity builds up in front of it a shock wave of heated and increasingly compressed air, and that with a sufficient velocity maintained to a sufficiently low altitude (i.e. air density) the meteorite shatters itself against this self-generated barrier. The calculations of Levin (quoted by Krinov 1960 p. 75) suggest that the air pressures generated could attain the static crushing strength of common rocks. Some writers have given prominence to heat stresses, but in view of the demonstrably shallow penetration of heat effects, fragmentation from this cause is likely to be confined to the loss of thin flakes and perhaps occasionally to a more complete fragmentation triggered by such losses. These general concepts apply to oriented stones (and conceivably also to a stone which happened to be rotating about an axis parallel to the line of flight), but such stones are a minority. In the more general case of stones rotating about any other axis or tumbling irregularly, the form of the shock wave and the direction of compression relative to the stone are continually changing. The situation of the meteorite may be compared with that of a ball compressed between a board and a table top, and forced to roll by movements of the board, movements which need not be constant either in speed or direction. Krinov (op.cit.) has drawn attention to the importance in the fragmentation process of these sharp variations in pressure on different parts of the meteorite.

The experimental work of Charles (1956) may be taken as an example of the difficulty of applying experimental results to a meteorite. Charles showed that for brittle material, equiaxial fragment shapes were favoured by high impact velocity. However, even the "low" velocity of his experiments involved impact times of only a few milliseconds. If the shattering of a meteorite involves the slow building up of pressure over a period of seconds or tens of seconds this is an exceedingly "low" velocity in the sense of the experiment. On the other hand, if a meteorite is tumbling rapidly, it might well be that even the "high" velocity conditions with exceedingly short impact times are encountered by a meteorite during atmospheric flight.

Not the least of the advantages of the controlled experiment is that the test piece may be shattered by a single blow and the fragments examined They frequently contain secondary i.e. internal, non-bounding fractures. A meteorite fragment containing secondary fractures will presumably have a much reduced crushing strength and be especially liable to further failure, perhaps only momentarily later when it adopts a suitable orientation. When fragmentations are separated by very short time intervals, it is not possible to distinguish between the products of the two events. Thus the application to meteorites of even the well established relationships of size distribution of products is also complicated by uncertainties.

The method and nomenclature of Frost (1969) will be followed in the treatment of size distribution. A Gaudin population of sizes resulting from high speed impact is described by the relation

$$y = 100\ (x/K)^m$$

where y is the cumulative weight percent finer than size x, and K and m are constants for any one population. For distributions of this type, the graph of log y against log x or against x expressed in phi units (i.e. $-\log_2 d$, where d is diameter in mm) will be a straight line with K

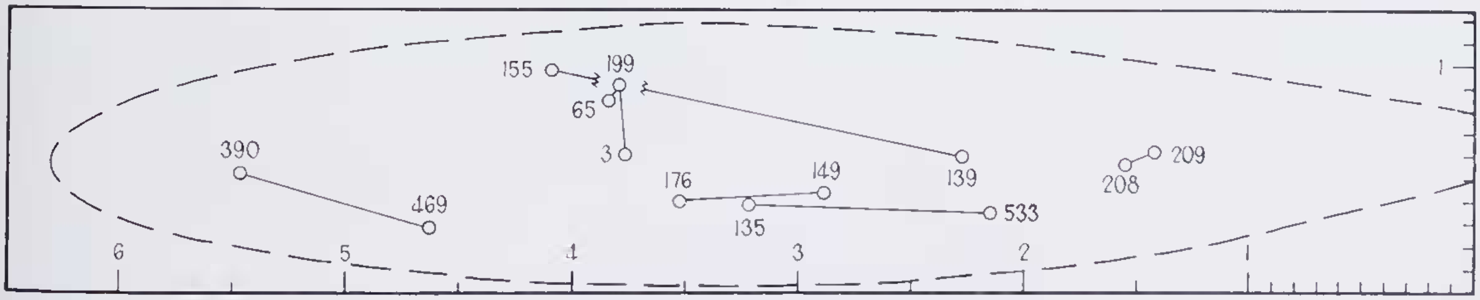

Figure 4.—Distribution of some fitting fragments (linked by lines) of the Mulga (north) meteorite, constituting partial minor distributions within the general stewnfield. Numbers along the lower and right-hand edges are kilometres west and north respectively of datum.

the maximum size and m a measure of the slope or sorting. Size is conveniently expressed in terms of an equivalent sphere. It may be deduced from the Gaudin equation that

$$d = -3.024 - 1.1073 \log_{10} M$$

where d is the diameter of an equivalent sphere in phi units and M is the mass of the stone in grams; the constant embodies the special case of the Mulga (north) shower, for which a density of 3.6 g/cm^3 has been used. Badly weathered material on the one hand and the freshest material on the other might differ by as much as 0.1 g/cm^3 from the adopted mean density figure, but the result is generally affected by only about ±0.01 phi unit.

Frost (op.cit.) has concluded that a first estimate of 0.5 for m for both meteoritic stones and irons is not unreasonable, and the value 0.5 will be used here in order that results are on a comparable basis. In fact, an estimate of m for Mulga (north) gives a somewhat lower value, though it is well within the range found by experiment.

Figure 5A is a simple frequency diagram for the numbers of stones of Mulga (north) falling within intervals of half a phi unit. Disregarding stones smaller than -3½ phi units (of weight less than 2.7g) and those larger than -6 phi units (weight greater than 500 g), both of which groups are probably inadequately collected, there remain five points of reasonable reliability on the diagram. The line of best fit for these points applied to the Gaudin distribution leads to an estimate for m of about 0.4.

Cumulative size distribution curves are shown in Fig. 5B. Curve No. 1, which was prepared when only 405 stones were known, has a steepness comparable with the curves figured by Dr. Frost, but with a greater regularity than most of them arising from the large numerical size of the sample. Assuming that m has a value of 0.5 and that departure of the curve from the straight line representing Gaudin distribution is related solely to non-recovery of fine material the non-recovery of Gaudin-distributed small stones may be calculated. From the ten percent ordinate, the non-recovery is (54-10) 100/(100-10), or about 49%.

Curve 2 of Fig. 5B represents the 781 pieces presently known, and shows the distinct improvement resulting from the additional collecting. The upper portion approaches the Gaudin distribution with slope 0.5 as shown by the straight line; the non-recovery figure on the same basis is only 34%. Considering that only the 13 largest stones of Mulga (north) attain the size of the smallest material graphed by Dr. Frost for showers such as Tenham, these results appear highly gratifying, but the comparison is not strictly valid. It is noted that the material of those showers generally showed only one or two of the surface types designated in this paper by P, S, T and U, and therefore they were not the products of a series of fragmentation events.

It would afford a more valid basis for comparison if the products of a single fragmentation of Mulga (north) could be singled out. This has

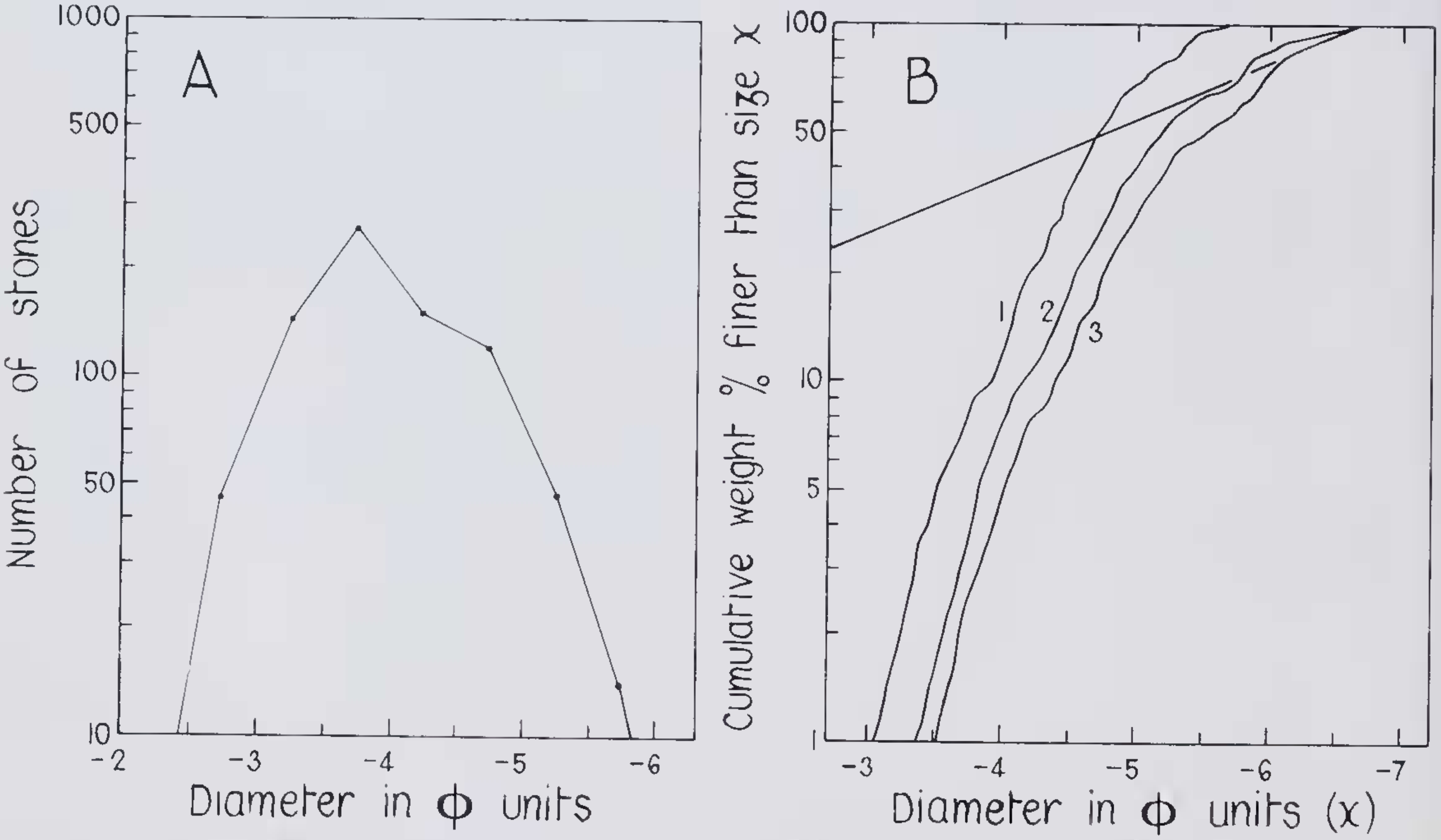

Figure 5.—A.—Simple frequency diagram for pieces of the Mulga (north) meteorite shower in $\phi/2$ (½ phi-unit) intervals. B.—Cumulative curves of size distribution for the Mulga (north) meteorite. No. 1.—for the 405 pieces known to December, 1970 (for clarity, this curve has been displaced 0.4 phi-unit to the left of its correct position); No. 2.—for all 781 pieces known to December, 1971; No. 3.—for pieces resulting from the initial fragmentation. The straight line is the Gaudin distribution of slope 0.5 positioned appropriately to curve No.2.

been attempted for the initial fragmentation, but rather sweeping assumptions are necessary —viz. that a single stone entered the earth's atmosphere, that the products of its initial fragmentation were capable of developing fully a primary crust, and that the products of later fragmentations were incapable of developing such crust on the newly exposed surfaces. Stones which would then qualify for inclusion in the sample are:—

1. Stones classed as CP.
2. Stones which can be restored to class CP, using diameters equivalent to the restored condition.
3. A few oriented stones of category CPS or similar, for which the surface of lesser crust development has been accepted as the result of sheltered location rather than of late exposure. Such stones may be identified in Table 2 by the weights and restored weights being identical.
4. Composite stones formed by uniting pieces found separated in the strewnfield, with or without restoration. Only three examples, one of which has a marginally acceptable degree of restoration, qualify for inclusion in this group.

Consideration was given to inclusion in the sample of small stones of inequidimensional shape of categories such as CPS. The doubt was that light stones of such shapes could maintain a sufficient velocity to develop fully a primary crust. However, the tabular pieces which are the majority of the group, might be only surface spalls from larger stones and the decision to exclude this small group cannot affect the cumulative weight curve significantly.

The acceptable groups comprise only 41% of the stones but nearly 60% of the mass, of which 1% is restored material. Twenty of the thirty heaviest stones belong to one or other of the first two groups. The mean weight of stones in the sample is 36 g compared with a mean weight for all stones of 25 grams.

Curve 3 of Fig. 5B thus purports to represent a sample of the products of a single fragmentation event. It is slightly steeper than curve 2 which represents all stones. The non-recovery figure on the same basis is 38% as against 34%. This slightly greater steepness is in accord with experimental experience (Gaudin and Hukki 1944), but the major problems of recovery of material and isolation of the sample from other products do not arise under controlled experimental conditions. Curve 3 is rather flatter than those figured by Frost (1969 Fig. 2), with which, if the exercise had been successful, a comparison would now be valid, but there is good reason to believe that it is not. For the sample to be fully satisfactory, it is desirable that only the largest products of the initial fragmentation should have been removed by secondary and later fragmentations. The removal of only the largest products from a Gaudin-distributed population of sizes does not affect the slope of the line but simply displaces it towards the smaller sizes. Clearly, the reassembled stones considered above range down to quite small size and none of them even approaches the size of the largest stone recovered. A portion of the sample with unknown size distribution has therefore been removed by the later events. The difficulty might be resolved by completely reassembling all broken material, but despite repeated trials, the reassembled stones constitute but an insignificant fraction of it. Though the isolation of a sample of products of the initial fragmentation might have been successful, it cannot be claimed that the sample is thoroughly satisfactory for use in this way.

The curves 1 to 3 of Fig. 5B were commenced from the relatively low 1% level because of the large number of small pieces known. Curve 2 is not greatly steeper in the 0.1%-1.0% range than in the 1%-10% range (it requires 36 stones to attain the 0.1% level). It is likely that the lower portions of these curves would not be significantly flattened by further collecting because there is no real difference between the lower parts of curves 1 and 2. There would be difficulty in detecting smaller material, particularly when it might be widely dispersed by atmospheric winds and weathered. It would be doubtfully advantageous to collect in the more genial winter season because past experience has been that the area is usually densely covered by tufted grasses of knee height or higher.

Field Distribution

Only qualitative and semi-quantitative observations are offered.

A simple conception of an elliptical strewnfield is that fragmentation during oblique approach results in an expanding cone of pieces which therefore meet the earth's surface in an elliptical area. The combined effects of gravity and air resistance, invariably present, result in some grading in the direction of flight, heavier fragments in general travelling further whilst light ones are more readily drawn into the vertical with free fall velocities. Other factors such as atmospheric winds also affect the distribution. Shape factors can be expected to have an influence, including the degree to which winds can affect the distribution. Of particular interest in the case of Mulga (north) are the effects of multiple fragmentation events. These later events at somewhat lower levels and steeper angles of approach can be expected to yield smaller and more equidimensional ellipses with less evident grading in the forward direction. Finally, when fragmentation occurs during vertically downward flight, dispersal may be expected over a circular area with grading (if any) a function of distance radially outward, and hence just as effective in the backward as in the forward direction.

Depending upon factors which could influence the altitude, timing and energy expended in fragmentation events, the individual areas of dispersal could be completely or only partially superimposed on others, or could occur quite independently at a distance. It seems likely that with sufficient data a general mathematical expression could be found to describe the distribution in the case of a single event, but for a shower such as Mulga (north), the distribution would involve the integrated result of a whole family of such expressions.

It is not possible to illustrate diagrammatically the full details of distribution of Mulga (north) because of the combination of an overall dimension exceeding 6000 m with interfragmental distances ranging down to less than one metre. Referring to the weight categories of Fig. 6 in descending order, 14 stones of the third category and 44 stones of the fourth category have been omitted from the figure (mostly from the western end); all 55 stones of weights 0.2-1.0 g have been omitted. The general increase in fragment weight to the east is evident in the diagram but is not as marked as might be expected for a relatively narrow ellipse. Multiple fragmentation and the loss of flakes from the surfaces are regarded as the two factors principally responsible for the large overlaps of the weight categories.

The distribution of the component parts of one of the re-assembled stones shows that heavier fragments are not necessarily found further along the line of flight. The composite stone 155/139/140 can be restored to class CP with reasonable confidence. No. 155 weighs more than 150 grams. The balance of the original stone could not have weighed more than 90 g, i.e. if all of the missing material was incorporated with Nos. 139 and 140, and this fell more than 1.8 km further east. The generally tabular shape of No. 155 might provide a partial explanation, but it seems likely that for the later fragmentation events as distinct from earlier ones in more nearly horizontal flight, the fortuitous directions of scatter from the point of burst may have a decisive influence on the points of fall. Note:—Stone No. 140 was belatedly recognised as an impact fragment of No. 139 and so also most likely is No. 141, though it cannot be fitted.

If the distribution of the oriented stones is to be used as an indication of the flight path, the ones most likely to be reliable are the 30 of category CP and 12 of other categories as follows:—CPT Nos. 69, 245, 341, 355, 370, 624, 634, 658, 815; CPS Nos. 260, 759; CPST No. 309. These 12 oriented stones require insignificant amounts of restoration, or in a few cases, have surfaces of lesser crust development attributable to sheltered location. This sample totalling 42 stones is rather inadequate for mathematical treatment, but from visual inspection of a plot of the sites there appeared no reason to change present concepts of the position of the axis of the distribution or the essentially west to east direction of flight. Indeed, for such a small number of stones, the plot has a surprising degree of resemblance to the general distribution.

The general trends of the lateral distribution were determined by dividing the strewnfield into transverse strips 1 km wide, each strip overlapping its neighbours by 0.9 km, and plotting the

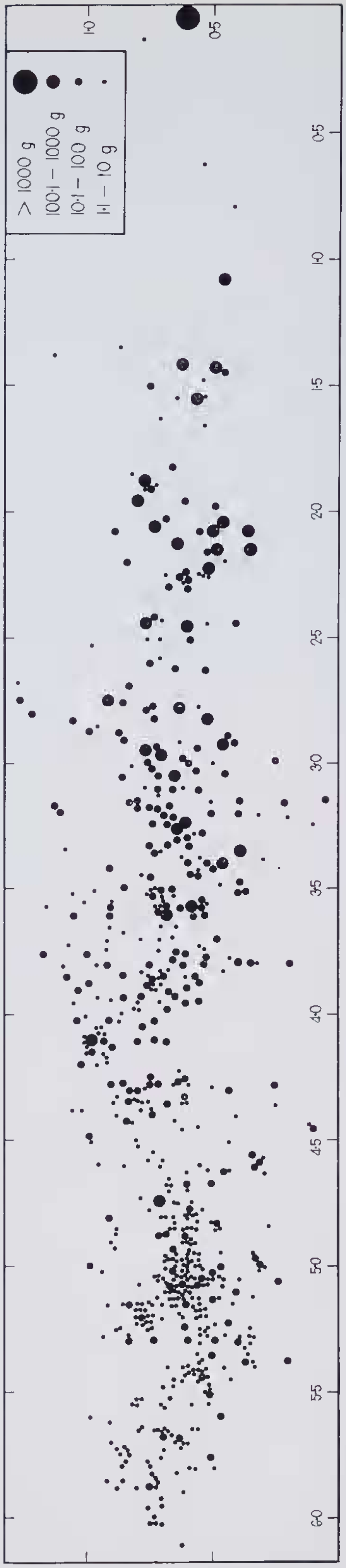

Figure 6.—Diagrammatic representation of the distribution of about 85% of the known pieces of Mulga (north) meteorite (for omissions, see text). Marginal figures along length and width of diagram are kilometres west and north respectively of the datum.

numbers of stones or other statistics at abscissae representing the mid-lines of each strip. The number of stones in each strip is a maximum near the western end of the strewnfield and declines rapidly eastward but with a distinct reversal and secondary maximum at 3.9 km W, where dense crowding may be seen in Fig. 6; the curve has the same general shape if stones/km^2 are plotted but the secondary maximum is less prominent. The weight of material in transverse strips is minimal near the western end and increases eastward, but with a marked inflection centred on about 4.8 km W to attain a maximum at 3.4 km W, and thereafter decreases rapidly; again, the asymmetry is retained on a weight/km^2 basis.

The mean weight of stones in transverse strips is minimal at the western end and increases steadily eastward. It is valid in this case to consider the CP stones separately on the same basis because the removal of some stones —not necessarily the largest—by further fragmentation does not affect the points of fall of other individuals. Stones requiring insignificant restoration may also be included in the sample but all others must be excluded because as complete individuals they would almost certainly have landed elsewhere. The resulting curves (Fig. 7) show clearly that there is a real difference between CP stones and the general sample. The curve for CP stones suggests some form of logarithmic relationship between mass and distance, but too much cannot be read into curves of means plotted at mid points. For the same reason, the complexities of the other curves cannot be interpreted as indicating two populations, though that might well be true.

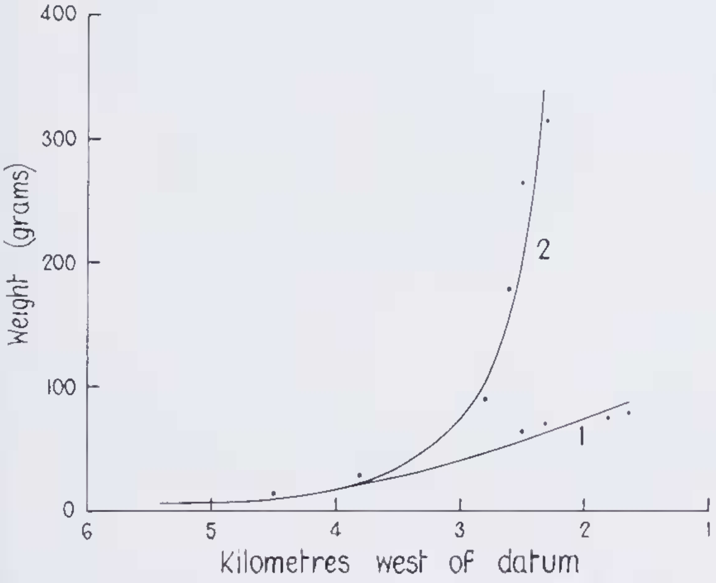

Figure 7.—Mean weights of stones of the Mulga (north) meteorite found in N-S strips 1 km wide, each strip overlapping the neighbouring strips 0.9 kilometre. Curve 1.—All stones; Curve 2.—Completely primary-crusted stones. Only points not falling closely on the curves are shown in the figure.

Some limited trials were made with scatter diagrams for individual stones and the best of these appeared to be that of log weight against distance when confined to CP stones (c.f. Frost op.cit.p.228), the "sorting factor" being from inspection of the order of 1.5. The detailed treatment of the distribution has, however, been left to the mathematical specialist.

Acknowledgments

I thank M. K. Quartermaine and T. G. Bateman whose energetic and voluntary search efforts were responsible for more than three quarters of the meteorite finds. I am especially grateful that they returned again to the area with me in 1971 whilst aware of the climatic conditions to be expected and of the severe limitations on water usage.

W.A. School of Mines vehicles were freely used on field work, the three earlier visits being made while the School was a branch of the Mines Department of Western Australia, the two most recent visits since the School became a branch of the Western Australian Institute of Technology.

Appendix

Weights, sites of find, and distribution in collections of the meteorites are given below. Some of the earlier recoveries made by School of Mines personnel have been either donated to or exchanged with the Western Australian Museum, and the later recoveries have been handed over in accordance with the Western Australian Museum Act of 1969 whereby the meteorites are Crown property and are vested in the Museum.

Mulga (south). See Table 3 .The second and sixth items of the table are in the W.A. School of Mines collection, the balance in that of the Western Australian Museum.

Table 3

Weight and locality details of Mulga (south) meteorite

Year of find	W.A.S.M. Catalogue No. or field No. (brackets)	Weight g	Westing km	Northing or Southing (S) km
1963	9584.1	59.5	ca.4.9	ca.0.7 S
,,	9584.2	52.6	ca.4.9	ca.0.7 S
,,	9584.3	16.2	ca.4.9	ca.0.7 S
1964	9738	76.2	ca.4.0	ca.0.55
,,	9739	26.0	ca.4.0	ca.0.55
,,	9740	28.5	ca.3.9	ca.0.1 S
,,	9741	18.9	ca.4.5	ca.0.8 S
,,	9742	20.2	ca.4.5	ca.0.8 S
1970	(110)	65.5	2.87	0.86
,,	(179)	112.0	3.94	0.59
,,	(323)	27.9	4.02	0.50
1971	(435)	26.8	5.06	0.41
,,	(449)	38.0	5.65	0.44
,,	(460)	2.9	4.84	0.28
,,	(468)	160.2	4.57	0.21
,,	(488)	32.6	4.25	0.25
,,	(506)	73.5	4.69	0.32
,,	(531)	1.5	2.22	0.40
,,	(532)	13.6	2.22	0.40
,,	(539)	19.4	1.40	0.51
,,	(558)	1.2	3.53	1.15
,,	(595)	1.3	1.55	0.56
,,	(667)	0.3	5.58	0.82
,,	(690)	19.5	5.64	0.69

Billygoat Donga. See Table 4. The main portion of the original stone found by T. and P. Dimer is in the W.A. School of Mines collection (9469), the other two pieces in the Western Australian Museum collection.

Table 4

Weight and locality details of the Billygoat Donga meteorite

Year of find	W.A.S.M. Catalogue No. or field No. (bracketed)	Weight g	Westing km	Northing km
1962	9469	142	ca.3.5	ca.7
1970	(225)	392.4	4.25	0.85
1971	(493)	98.4	4.42	0.69

Mulga (north). Full details of the material set out in the pattern of Table 2 are available on application to the Director, Western Australian Museum, Perth, Western Australia. Ownership follows:—

Smithsonian Institution: Field Nos. 72-84.

W.A. School of Mines: Field Nos. 1-5, 7-10, 12, 14-21, 23-36, 38-43, 45, 46, 48 (part), 49-59.

Western Australian Museum: The balance of the material.

Mulga (west). Field No. 430, weight 169.2 g, found at 5.29 km W and 0.19 km N in 1971 is in the Western Australian Museum collection.

References

Charles, R. J. (1956).—High velocity impact in comminution. *Mining Engineering* 8: 1028-1032.

Cleverly, W. H. (1965).—New discoveries of meteoritic stones north of Haig, Western Australia. *Aust. J. Sci.* 28: 126-128.

Foote, W. M. (1912).—Preliminary note on the shower of meteoric stones near Holbrook, Navajo County, Arizona. *Amer. J. Sci.* 34: 437-456.

Frost, M. J. (1969).—Size and spacial distribution of meteoritic showers. *Meteoritics* 4: 217-232.

Gaudin, A. M. and Hukki, R. T. (1944).—Principles of comminution-size and surface distribution *Amer. Inst. Mining and Metallurgical Engineers Tech. Publ.* No. 1779.

Krinov, E. L. (1960).—"Principles of Meteoritics". (Pergamon, London). Translation.

Lang, B. and Kowalski, M. (1971).—On the possible number and mass of fragments from Pultusk Meteorite Shower, 1868. *Meteoritics* 6: 149-158.

McCall, G. J. H. (1968).—First supplement to Western Australian Museum Special Publication No. 3 Catalogue of Western Australian Meteorite Collections. Western Australian Museum, Perth.

McCall, G. J. H. and Cleverly, W. H. (1968).—New stony meteorite finds including two ureilites from the Nullarbor Plain, Western Australia. *Miner. Mag.* 36: 691-716.

——————(1970).—A review of meteorite finds on the Nullarbor Plain, Western Australia, including a description of thirteen new finds of stony meteorites. *J. Roy. Soc. W. Aust.* 53: 69-80.

McCall, G. J. H. and deLaeter, J. R. (1965).—Catalogue of Western Australian meteorite collections. *Spec. Publ. Western Australian Mus.* No. 3.

Mason, B. (1962).—"Meteorites". (John Wiley, New York).

Nininger, H. H. and Nininger, A. D. (1950).—"The Nininger Collection of Meteorites". American Meteorite Museum, Winslow, Arizona.

Pettijohn, F. J. (1957).—"Sedimentary Rocks". 2nd Ed. (Harper, New York).